②

DTIC FILE COPY

RESEARCH AND DEVELOPMENT TECHNICAL REPORT

CECOM-TR-88-2

AD-A197 473

A COMPARISON OF PROPAGATION MODEL PREDICTIONS WITH EPLRS UHF NETWORK MEASUREMENTS

WILLIAM M. BRENNAN

PAUL F. SASS

CENTER FOR C3 SYSTEMS

AUGUST 1988

DISTRIBUTION STATEMENT

Approved for public release;
distribution is unlimited.

CECOM

US ARMY COMMUNICATIONS-ELECTRONICS COMMAND

FORT MONMOUTH, NEW JERSEY 07703-5000

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ADA197473

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) CECOM-TR-88-2	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Army Communications-Electronics Cmd (CECOM), Ctr for C3 Systems 6b. OFFICE SYMBOL (If applicable) AMSEL-RD-C3-AC-B	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Center for C3 Systems ATTN: AMSEL-RD-C3-AC-B Fort Monmouth, NJ 07703-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
A COMPARISON OF PROPAGATION MODEL PREDICTIONS WITH EPLRS UHF NETWORK MEASUREMENTS (U)

12. PERSONAL AUTHOR(S) William M. Brennan, Paul F. Sass

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM ______ TO ______	1988 August	19

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
17	02	01

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
UHF Radio; Probability Distribution; Propagation Models; Free Space Loss (FSL); Delta H

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report presents the results of a comparison between measurements at White Sands Missile Range (WSMR), New Mexico, and several propagation prediction models. One of these models is called Ground Network Communications Model (GNCM), which uses the point-to-point path loss prediction capability of the Irregular Terrain Model (ITM, or "Longley-Rice" model). The analysis was completed using measurement data taken at WSMR with a 41-node EPLRS (Enhanced Position Location and Reporting System) network. Several models are compared with the measurements, demonstrating the reliability of propagation models.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL William M. Brennan	22b. TELEPHONE (Include Area Code) (201) 532-0164 22c. OFFICE SYMBOL AMSEL-RD-C3-AC-B

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

CONTENTS

FIGURES

A COMPARISON OF PROPAGATION MODEL PREDICTIONS WITH EPLRS UHF NETWORK MEASUREMENTS

INTRODUCTION

For some time there has been a controversy over the applicability of propagation models such as the Irregular Terrain Model (ITM, originally called "Longley-Rice" model) for predicting the performance of distributed UHF ground networks with low elevation antennas. Measurement efforts conducted over the years have produced samples statistically inadequate to support a conclusive comparison among the various models. This report presents a comparison of several path loss prediction models with recently acquired measurement data taken with the U.S. Army's Enhanced Position Location and Reporting System (EPLRS) equipment deployed in a test area at White Sands, New Mexico. The measurements provide a unique opportunity to examine radio path loss encountered on the individual links of a distributed radio network in the 420-450 MHz band. A total of 799 link measurements analyzed in this report comprise the 41 node EPLRS network, all deployed with low elevation (2 meter) omni-directional antennas and transmit powers of nominally +50 dBm. Measured data is compared to predictions made with Center for C3 Systems' Ground Network Communications Model (GNCM), a network version of ITM which uses the "point-to-point" path loss prediction of the ITM, as well as with several simpler propagation models including "Free Space Loss" (FSL) and "Plane Earth ($1/r^4$)" propagation.

THE MEASUREMENT SCENARIO

A representative EPLRS network was deployed in a 6 km x 15 km area of the White Sands Missile Range (WSMR). Measurements were conducted by USA CECOM, (PM PLRS/TIDS), and USA ERADCOM (EWL) with contractor support from SRI International and Eagle Technology. In these measurements a calibrated EPLRS simulator (transmitter) was moved on a predetermined course among 41 presurveyed locations. Receivers moved among the 41 locations provided measurements

of signal power in the EPLRS receiver front end. By comparison with calibrated signal sources, a measurement of received signal level was made at 3 frequencies in the EPLRS band (420-450 MHz) at every location. For the purpose of this report these three measurements were replaced by a single value of measured received signal power. It is noted, however, that the frequency-to-frequency variation at any site never exceeded 1 dB. Antennas used for the measurements were EPLRS manpack antennas (2 dBi) at approximately 2 meter elevations.

Measured signal power P_R is converted directly into measured path loss L_B by the following link budget:

$$P_R = P_T + G_T + G_R - L_T - L_R - L_B \qquad (1)$$

$$L_B = P_T + G_T + G_R - L_T - L_R - P_R \qquad (2)$$

where:

P_T = +50 dBm (100 Watts) = transmit power
$G_T = G_R$ = 2 dBi = Ant. gain (XMTR,RCVR)
$L_T = L_R$ = 0 dB = Line loss (XMTR,RCVR)

Several items are worth noting in the selected deployment. First, of the possible 820 links in the 41 node EPLRS network, only 799 links yielded measurement data. Therefore, only the 799 good links will be compared among the different models in this report.

Secondly, links are relatively short. Due to the limitations in available real estate and logistics at White Sands, 41 EPLRS nodes were distributed over a 90 km^2 area, shown in Figure 1, resulting in an average link length of only 5.02 kilometers. Figure 1 shows the 'good' links or the network's connectivity as predicted by GNCM. The distribution of link lengths in the White Sands EPLRS measurements is shown in Figure 2. The x-axis is the link distance in kilometers and the y-axis is the frequency of occurrence.

Lastly, White Sands terrain is quite flat. Figure 3 is a distribution of terrain roughness, measured by delta h, derived from digitized topographic data resident in Center for C3 Systems' GNCM. The units of this figure are the same as those of Figure 2. The average delta h value is 16.51 meters with a small standard deviation. This average is over the 799 'good' links, indicating an exceptionally flat, uniform terrain. Also, there is very little, if any, vegetation in the test area. This, of course, is advantageous

for the comparison with predictions, since the prediction models used make no provisions for foliage.

GNCM PREDICTIONS

The objective of this report is to compare EPLRS measurements at WSMR with predictions made by GNCM (Ref. 1) and other propagation models. As noted, the dense deployment of EPLRS units in these measurements was of some concern, since the ITM (which GNCM uses) is not typically thought to be accurate for link lengths less than 1 km. In the EPLRS deployment considered, 44 links out of 799 measured were less than 1 km in length.

Figure 4 is an "error" curve comparing the path loss measurements (WSMR) with the path loss predictions (GNCM) for every measured link in the network. The units for both axes are in dB. Those values above the diagonal line indicate that measured (WSMR) loss was greater than predicted (GNCM) loss for the same link. Only links which had losses both measured and predicted were compared (799 out of a possible 820). The other 21 links were deleted because measurement data was not available. In 54% of the links plotted, the predicted value was higher than the measured value. In 43% of the links, the measured value was higher than that predicted. This comparison indicates a small average "bias" of 2.44 dB for the 799 links that were compared. Figure 4a is the Error Probability Distribution between the White Sands measurement data and the GNCM prediction data. The units for this figure are in dB. If we assume the plot is generally Gaussian shaped, 95% of the errors are within +/-2 standard deviations (+/- 24 dB). The average error between the two groups of data is 2.44 dB and the standard deviation is 12.18 dB.

Figure 5 presents an analysis of this prediction "error" as a function of path length. This comparison is important because it reveals any obvious "trends" to the predictions, as well as any dependence on link distance. One such trend is the wide variation of path loss between GNCM and the WSMR measurement data at short link lengths.

PREDICTION WITH OTHER MODELS

Other propagation models can be applied to the prediction of UHF radio network performance. One such model is a "rule of thumb" used by some scientists for a preliminary analysis of JTIDS performance. This "rule of thumb" uses

Free Space Loss +15 dB as an estimate of path loss. Others include Free Space Loss ($1/r^2$), plane earth ($1/r^4$) (ref. 2), and the Longley-Rice "area" model (Ref. 3). None of these models uses specific terrain information (i.e., path profiles) in their prediction of path loss. Only the "area" model uses an area estimate of terrain roughness in predicting loss. Figure 6 presents a summary of the four different propagation prediction models considered in this report. Figure 6 compares all the models to the measured (WSMR) data, as well as to GNCM predictions. One should keep in mind that the area in which the field measurements were taken is extremely flat with no foliage. The three "Rapit" predictions refer to the Longley-Rice "area" model, in which three predictions were run for each link: a low, medium, and a high prediction value, corresponding respectively to a 10%, 50%, and 90% statistical quantile for the path loss prediction on each link. This model uses path length and an "area" terrain roughness factor (delta H) in its calculations. Therefore, for networks with low antennas in very flat terrain, the median "area" model prediction (50% quantile) is expected to agree with predictions using the point-to-point model (GNCM).

Another model which relies on path length alone to predict path loss is the plane earth ($1/r^4$) model (Ref 2). Figure 6 is a statistical comparison of the different models. (The units of this figure are also in dB.) Figure 6 shows that $1/r^4$ yields path loss predictions comparable in accuracy to median Rapit values (i.e., 50% quantile) and GNCM. The average prediction error using "plane earth" is 3.24 dB for the 799 links measured. However, the standard deviation for plane earth predictions is from 1.5 to 2.5 dB larger than any of the other models.

A final comparison is made with Free Space Loss. Measurements on the average are nearly 30 dB greater than Free Space Loss, with a standard deviation approximately the same as that of the other models. This suggests that for UHF deployments with short paths, low antennas, and smooth terrain, an average of 30 dB excess (above free space) path loss may provide a reasonable estimate, certainly no worse than any of the other models considered. This may prove to be a useful simplification for some network performance studies.

Figure 7 plots Free Space Loss, plane earth ($1/r^4$), and the Longley-Rice "area" model results against the actual WSMR measurements. Figure 8 plots the GNCM predictions against those of the other models.

Figures 7 and 8 reveal a phenomenon that has been suggested a number of times in the past: the variance of the predicted values (using the ITM-derived GNCM) appears to be less than that of the measured data. In fact, the statistics summarized in Figure 6 indicate that WSMR data was spread with a standard deviation of 14.07 dB. All the predictions, with the exception of plane earth, produced significantly lower variances. Predictions with GNCM (i.e., point-to-point ITM) were distributed with a variance 8.5 dB less than the measurements themselves. This may lend support to the contention that the prediction models still do not accurately represent the random variability observed in experimentally measured real-world ground-to-ground propagation data. In many cases, actual measurements repeated over two days on identical links produced results varying by as much as 47 dB. This contributed to the unusually large variance observed in the measured data.

CONCLUSIONS

Network measurements made with EPLRS radios at 420-450 MHz, low antennas and short path lengths dispersed over a 6 km x 15 km area of White Sands Missile Range have demonstrated good agreement with GNCM path loss predictions based on the ITM "point-to-point" propagation path loss model. Prediction "errors" (differences between measured and predicted values) are approximately normally distributed with an average bias of 2.44 dB, and a standard deviation of 12.16 dB. Predictions were equivalent in "accuracy" to median area model predictions, and somewhat better than smooth earth predictions. An average of 30 dB above Free Space Loss is suggested for the limited type of UHF deployments considered in this report, namely, smooth terrain, short paths and low antennas with no foliage obstruction. And, finally, point-to-point predictions using all propagation models appear to exhibit a variance significantly lower than the measurements themselves.

REFERENCES

1. Sass, P., "Connectivity Analysis of UHF Ground Radio Networks", US Army Technical report, CECOM-TR-84-2, April 1984.

2. Bullington, K., "Radio Propagation Fundamentals", Bell System Technical Journal, May 1957, pp 596-597.

3. Hufford, G.A., Longley, A.G., Kissick, W.A., "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode", NTIA Report 82-1 ITS, Boulder, CO, April 1982.

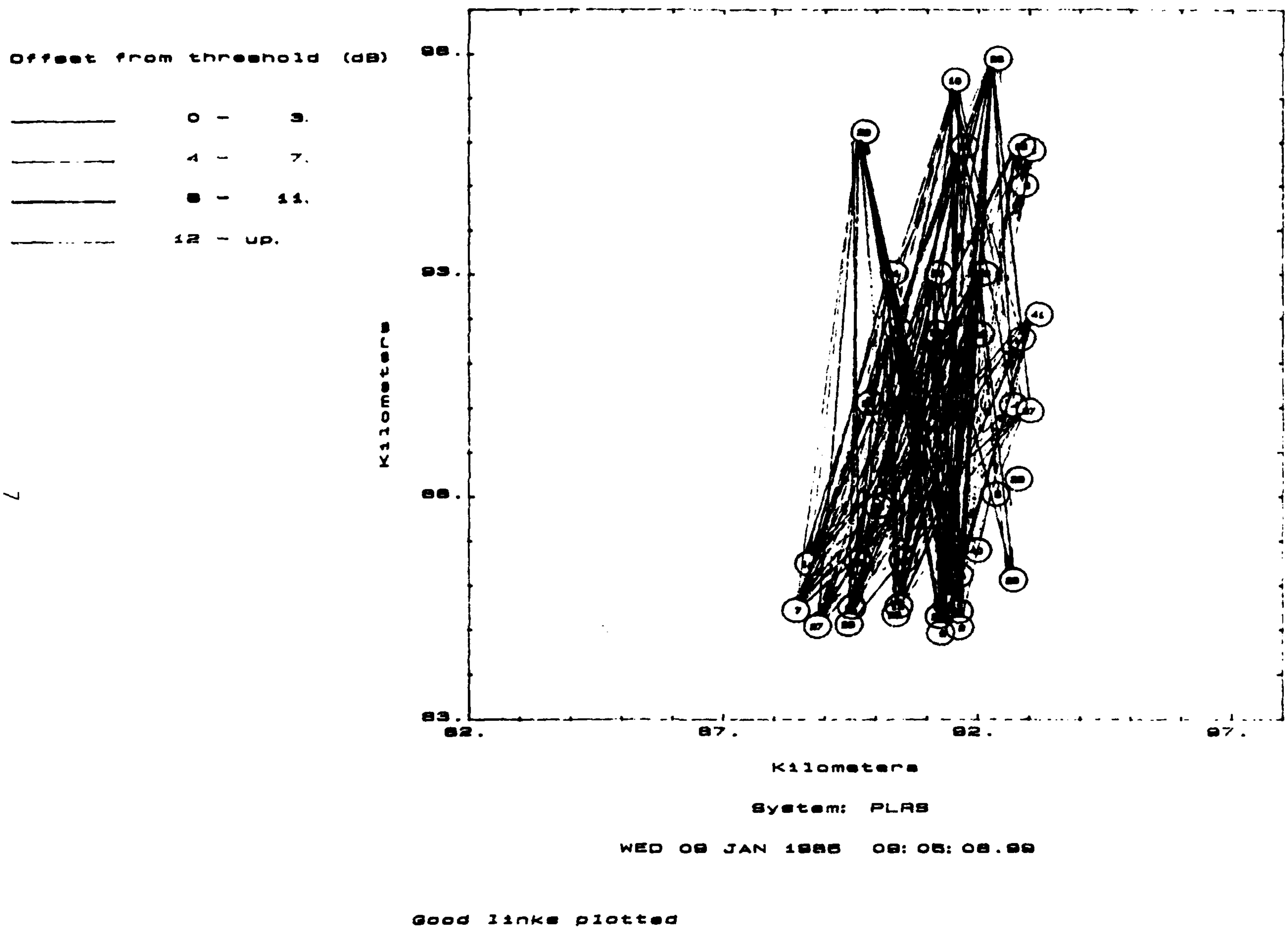
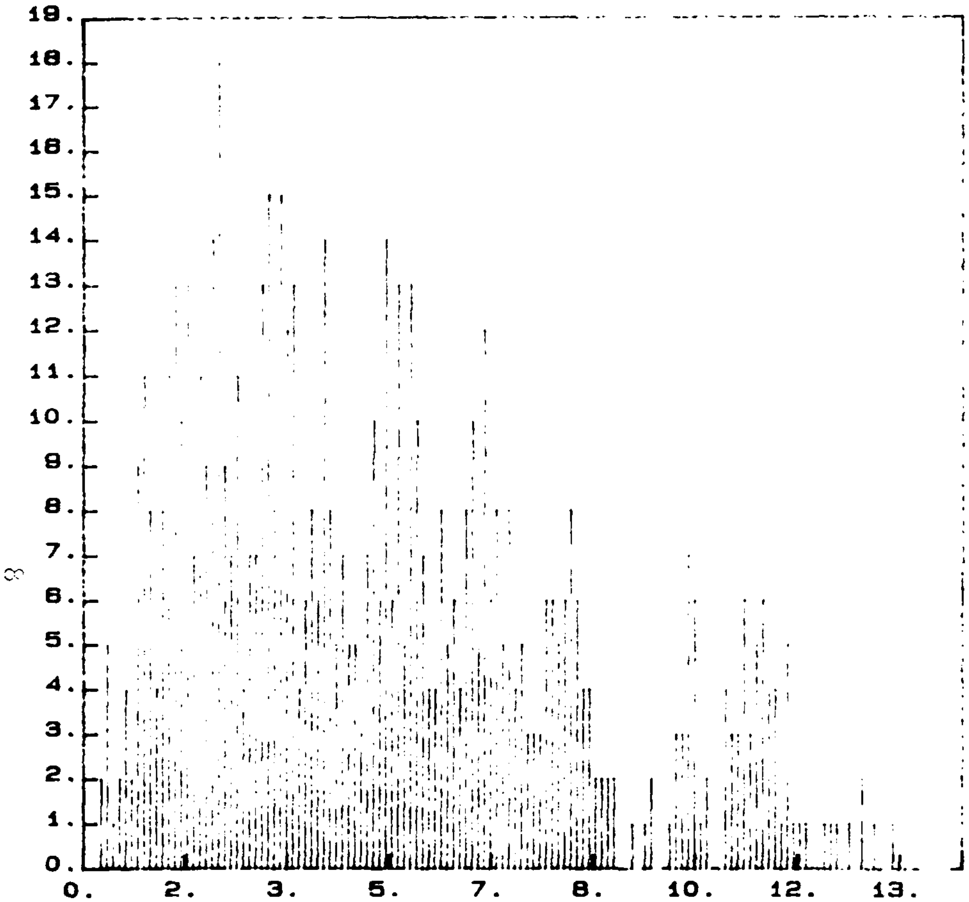


Figure 1. EPLRS network containing 41 nodes.

Link Distance (kilometers)



System Characteristics:

Location: White Sands, N.M.

Freq. (MHz): 435.00

Lat: 32.52

Lon: -108.1

XMTR Pwr (watt): 100

RCVR Sens (dB): -95.00

Antenna:

Type: OMNI

Gain (dBi): 2

Height (m): 2

Line Loss (dB): 0

Plot Parameters:

Average = 5.02

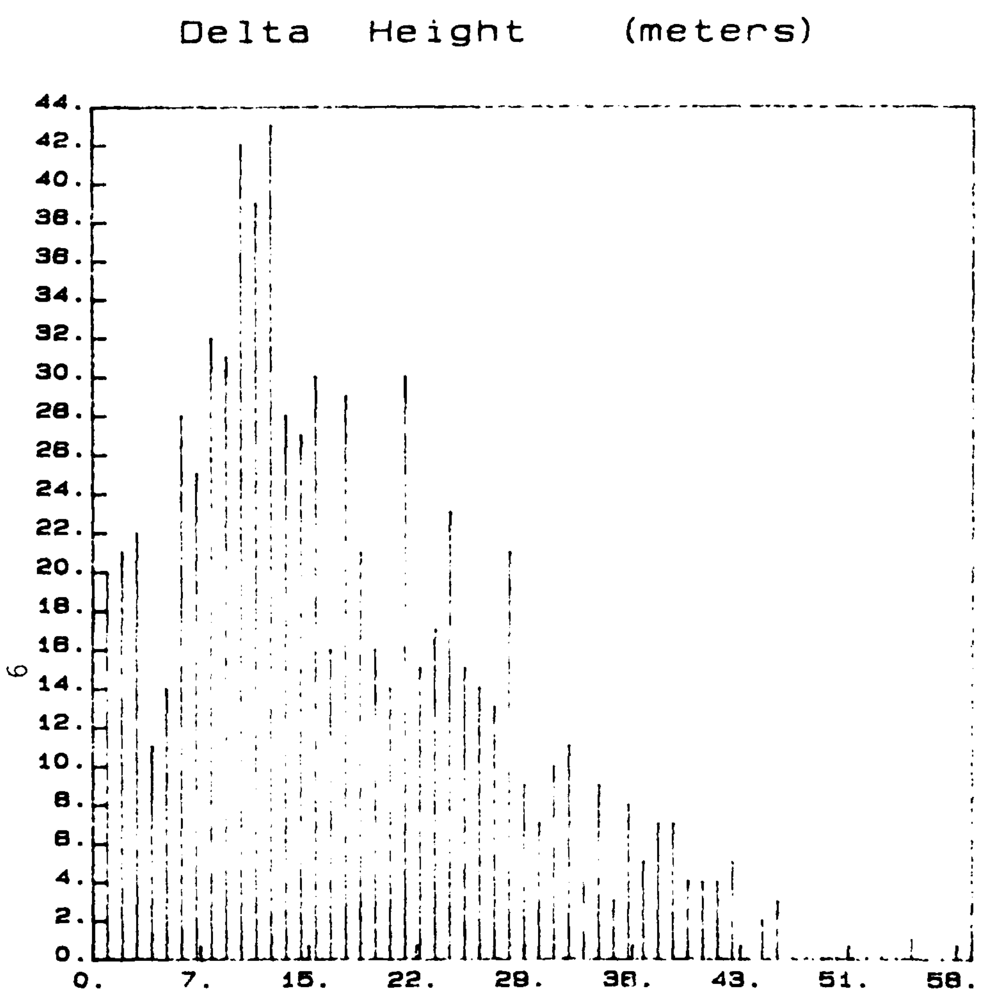
Std. Dev. = (+/-) 2.81

Number of links = 817

Average Network Degree = 39.85

# of nodes in network = 41

Figure 2. Distribution of Link Lengths.



System Characteristics:

Location: White Sands, N.M.

Freq. (MHz): 435.00

Lat: 32.52

Lon: -106.1

XMTR Pwr (watt): 100

RCVR Sens (dB): -85.00

Antenna:

Type: OMNI

Gain (dBi): 2

Height (m): 2

Line Loss (dB): 0

Plot Parameters:

Average = 18.51

Std. Dev. = (+/-) 8.61

Number of links = 817

Average Network Degree = 39.85

# of nodes in network = 41

Figure 3. Distribution of Delta H values.

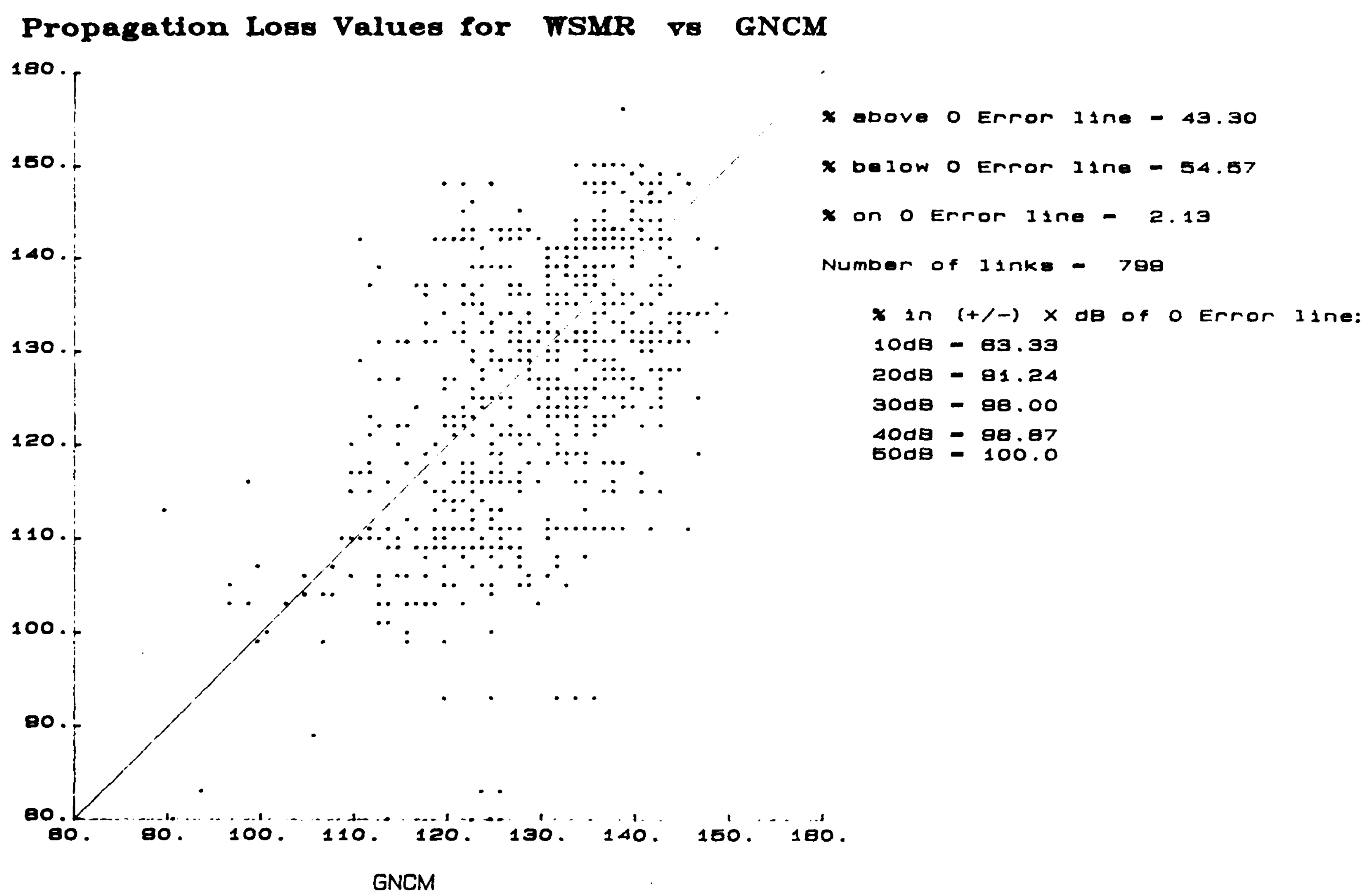


Figure 4. Prediction Error curve.

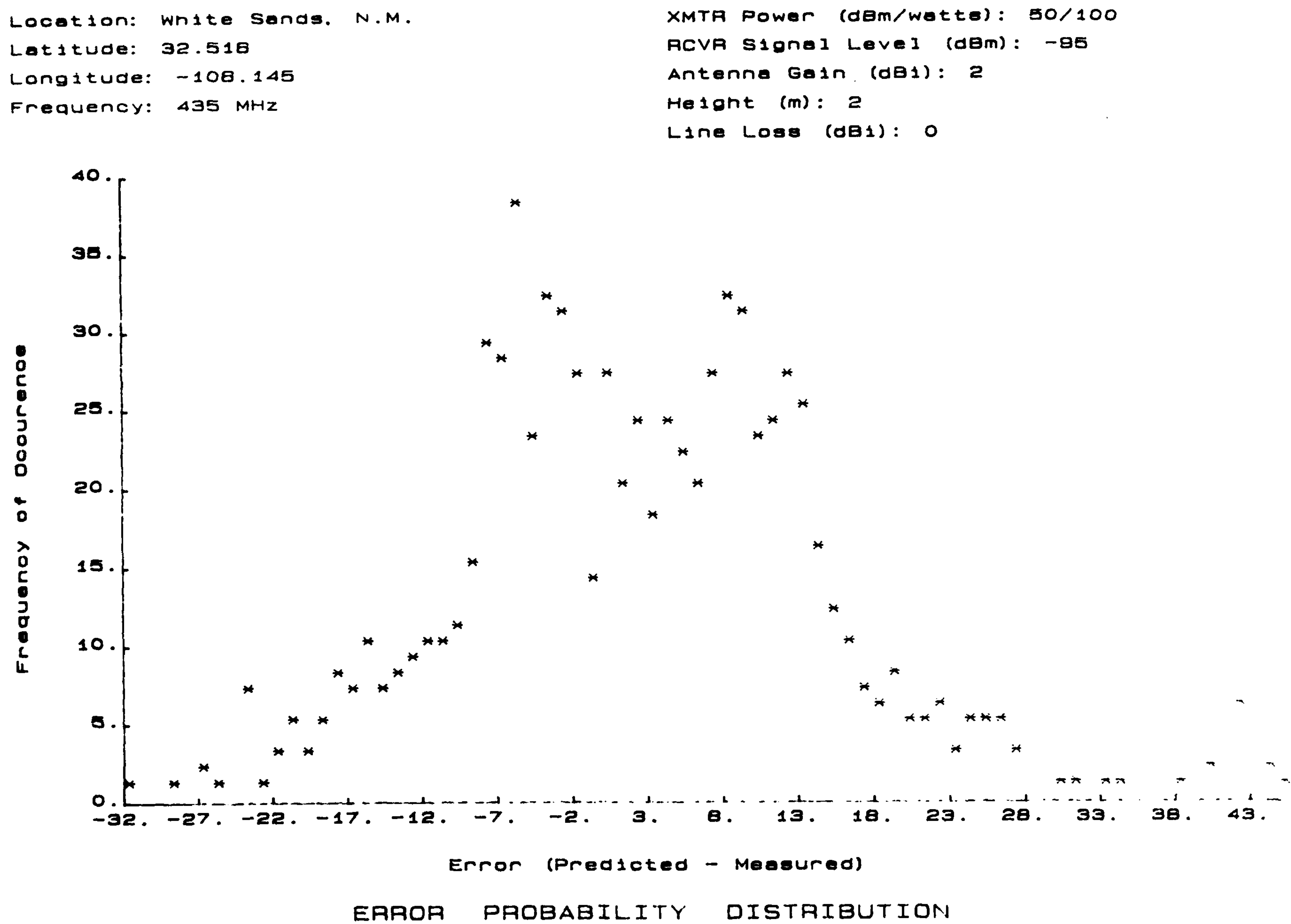


Figure 4a. Error Probability Distribution.

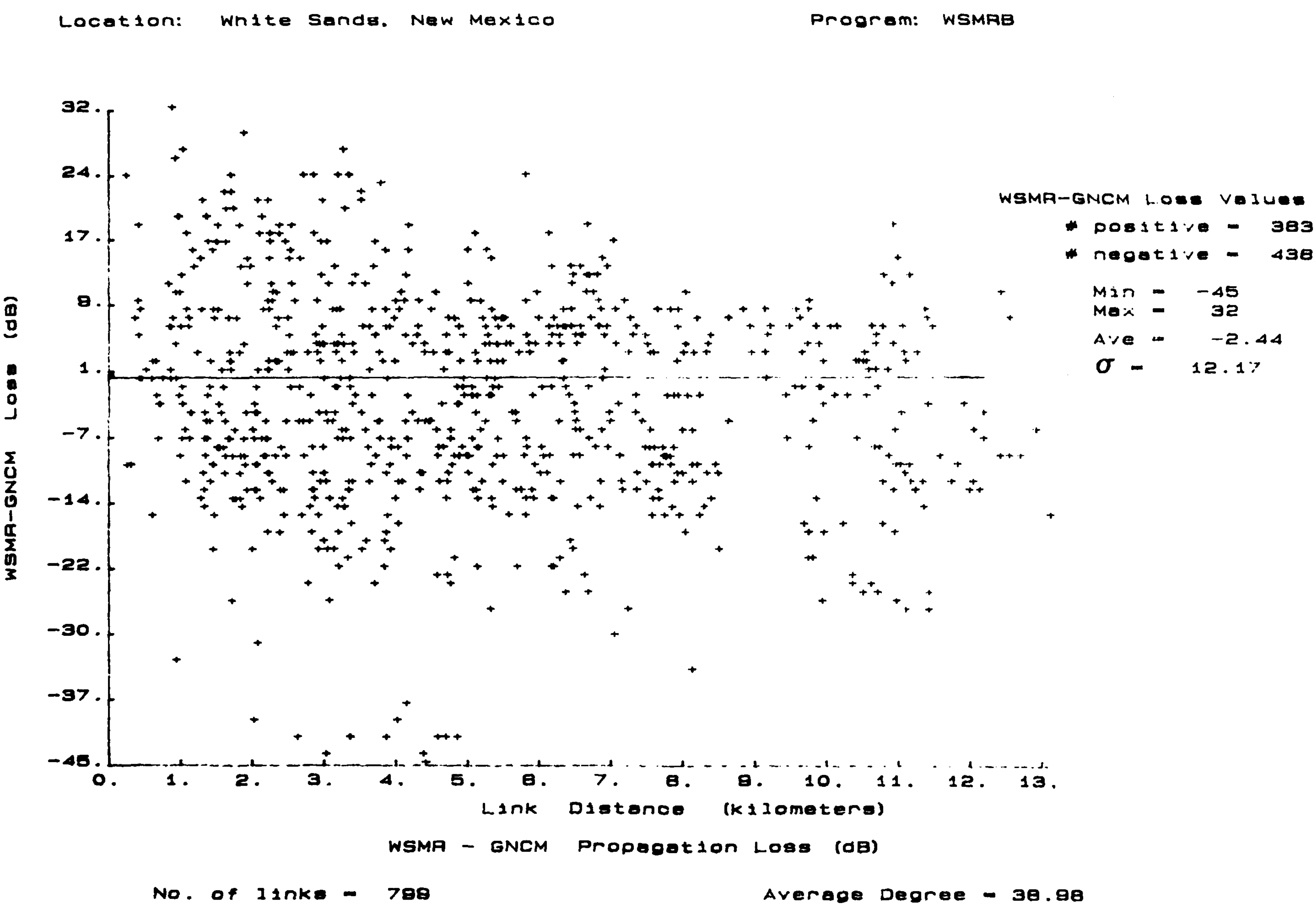


Figure 5. WSMR-GNCM Propagation Loss vs Link Distance.

MEASUREMENTS	Original Values				Original – WSMR				Original – GNCM			
	Max	Min	Average	STD	Max	Min	Average	STD	Max	Min	Average	STD
WSMR	156	60	126.55	14.07	0	0	0.00	0.00	32	−45	−2.44	12.16
MODELS												
GNCM	149	89	129.07	9.80	45	−32	2.44	12.16	0	0	0.00	0.00
1/R**4	156	106	130.00	14.64	53	−40	3.24	14.65	23	−17	−0.93	7.87
RAPIT (low)	142	103	120.88	11.46	42	−45	−5.78	13.24	14	−22	−8.17	5.71
RAPIT (med)	150	111	126.77	11.33	50	−37	2.10	13.16	22	−14	−0.29	5.57
RAPIT (high)	157	120	137.25	11.05	56	−26	10.57	13.08	31	−5	−8.17	5.47
FSL	108	71	97.25	6.62	19	−56	−29.31	12.23	−16	−43	−31.78	4.61

Figure 6. Comparisons (dB) between Models and Measurements.

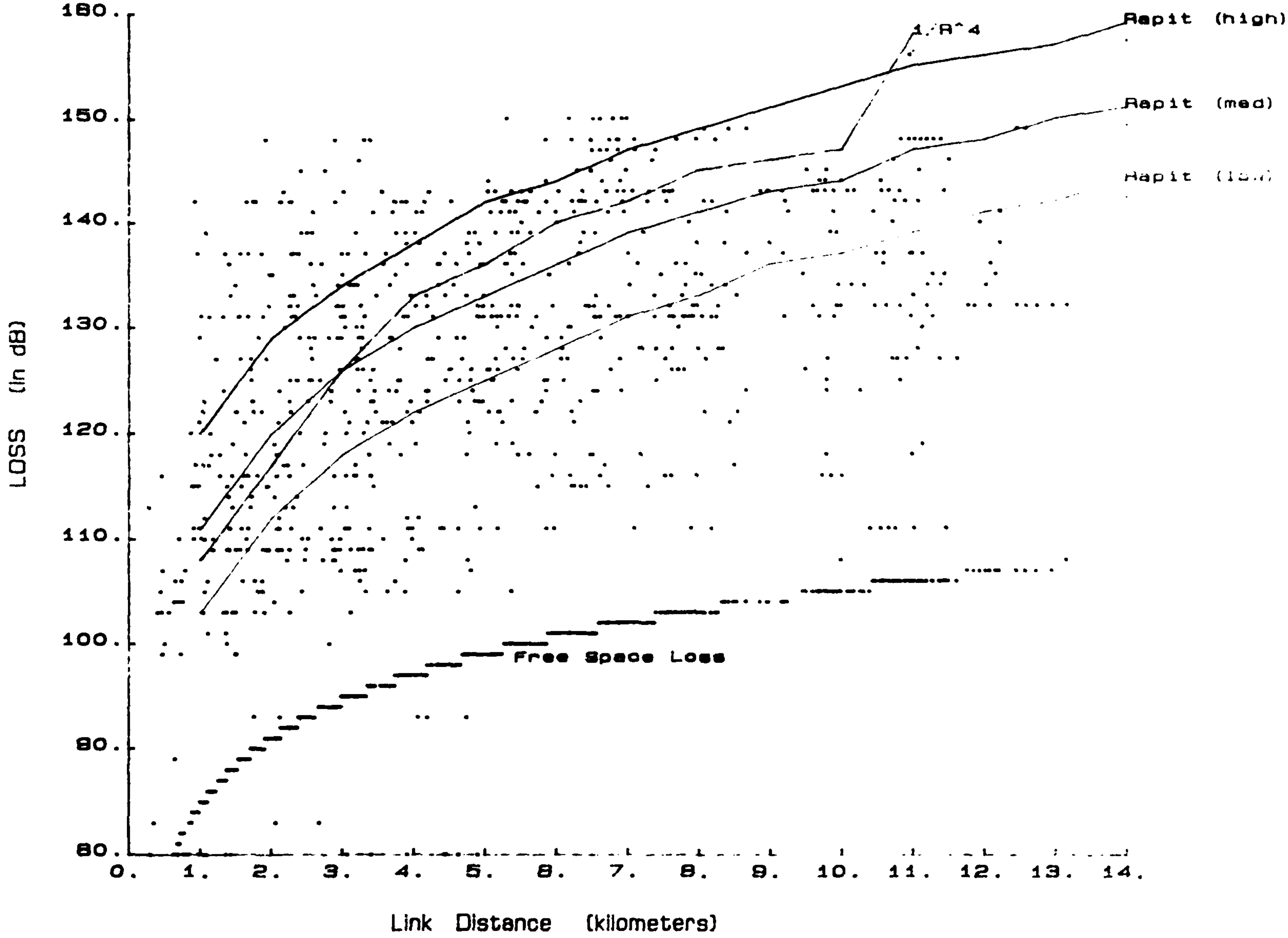


Figure 7. WSMR Path Loss vs Link Distance.

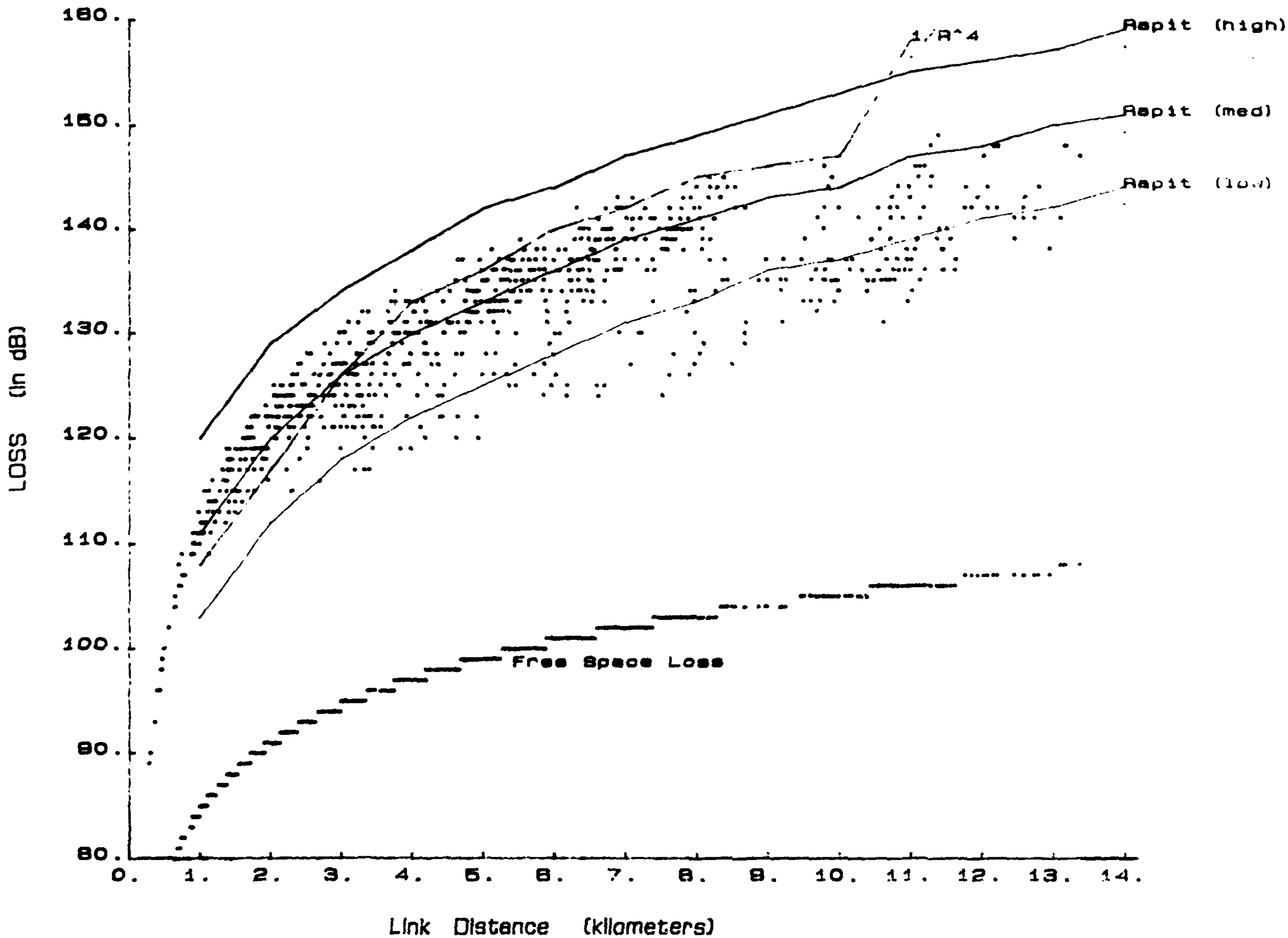
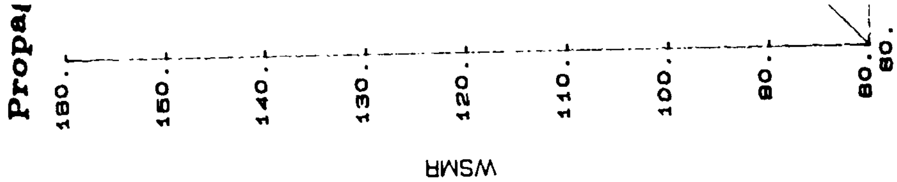


Figure 8. GNCM Path Loss vs Link Distance.


WSMR